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THE MODERN FIRE ENGINE

By PROF. K. W. STINSON, *Department of Mechanical Engineering*

THE first fire engines of which we have any knowledge were built and operated by the Greeks and Romans about 50 B. C. These pumps were large syringes and each one required three men to operate it. This syringe type was followed closely by a double-piston pump mounted on wheels. This pump was hand-operated and even today, in many parts of the world, outlying districts have no other means of fire protection.

About one hundred years ago the first steam-driven fire engine was built and this was followed by rapid development of the pump as well as the boiler and engine. The small sizes of these engines were drawn by hand while the larger engines were horse-drawn.

The boilers were fired with coal and were perfected to such a degree that from 100 to 200 pounds per square inch could be developed in the boiler in from six to ten minutes from the time that the fire was started. The steam engine and the pump were usually of the opposed-piston type with a steam piston and a water piston on each rod. Some of these engines were equipped with flywheels. There were two double-acting steam cylinders and two double-acting water cylinders on the majority of engines. The piston pump was practically the only type of pump used on steam-driven fire engines. Rotary pumps, however, were used by at least one concern.

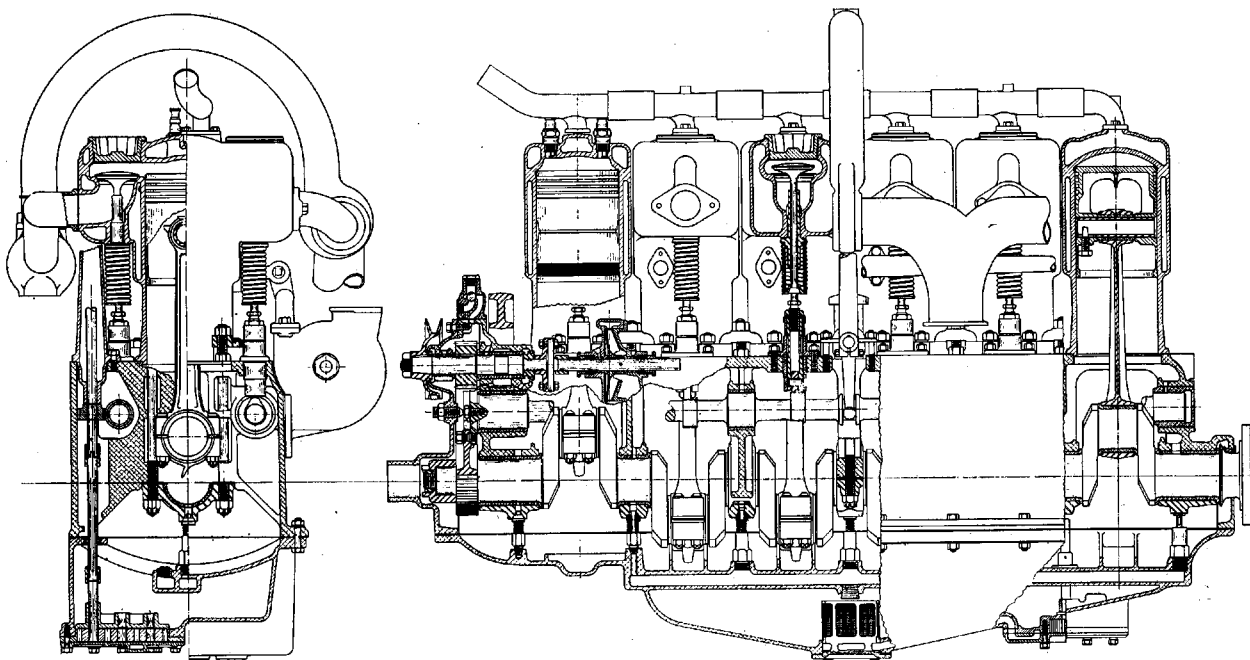
Some twenty years ago, attempts were made to propel the steam fire engine by its own power. This type of drive was not very successful due to a somewhat crude method of operation and also to the fact that, unless steam was kept in the boiler at all times, the engine could not start for the fire for perhaps five minutes after the alarm was received.

Soon the steam fire engines were drawn by gasoline-engine tractors, many of which were mounted on only two wheels, the unit replacing the front wheels of the fire engine. The power was transmitted through the

front wheels, and brakes were mounted on these as well as on the rear wheels. This is the first application of brakes on all four wheels known to the writer. The brakes, however, were not applied on all wheels at one time. This arrangement of brakes caused many serious accidents due to faulty operation. If the brakes on the front wheels were applied suddenly, the wheels would lock and cause the machine to skid, while the driver had absolutely no control over it.

Along with the conversion of the steam fire engine to a self-propelled vehicle came the first of the gasoline fire engines. Several manufacturers were attempting to build fire engines with a gasoline engine to operate the pump as well as drive the apparatus on the road. The gasoline engine and automobile of twenty years ago were not very dependable when compared to their present-day performance. This condition caused the gasoline fire engine to be considered unfavorably in comparison to the steam-driven. However, the development of alloy steels and the great advance made in automotive design raised the standing of this new type of fire engine until today it has replaced practically all steam fire engines.

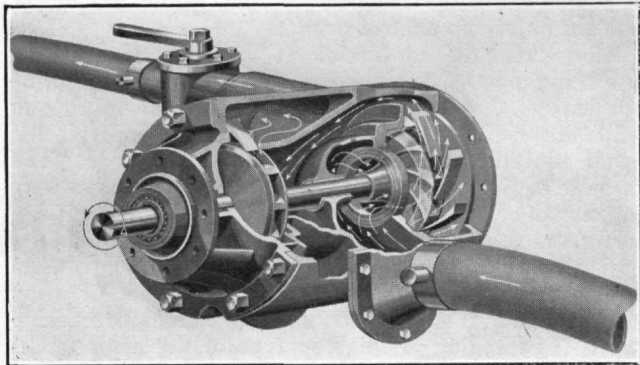
The rise of the gasoline fire engine has been a very noteworthy engineering achievement as the problems encountered were, in many cases, much different from those of the automobile industry, although they might appear at first to be practically the same. The one point that is foremost in fire-engine design is dependability,—not the cheapest, but the best,—not the lightest weight possible, but strength at any cost. Engine proportions that were very satisfactory for the automobile were not suitable for such service. The bearings were too small, the crank shaft was not strong enough, and many other parts would not stand up under the severe conditions of operation encountered in fire service. Approximately these same conditions were being encountered at this time in the development of the airplane engine. The



Sectional View of Modern Fire Engine.

airplane engine differed from the fire engine in that weight is one of the primary points to be considered.

The automobile engine is operated most of the time at from one-quarter to one-half of full throttle opening. In the cases of the airplane engine and the fire engine, the throttle is wide open much of the time. This condition of operation necessitates many differences in design and manufacture of fire engines from those employed in the manufacture of automobile and truck engines. It has been necessary for the manufacturers of gasoline-operated fire engines to carry on much research and development work in order to overcome the troubles encountered when operating under such extreme condi-



tions. The result has been dependable fire engines,—not trucks, not pleasure cars, but machines built from the ground up for a specific job, fire-fighting.

The fire engines of today vary in size from about 400 gallons per minute to 1,500 gallons per minute when pumping at a pressure of 120 pounds per square inch. Some smaller pumps will be found mounted on various truck chassis. The fire engines just mentioned require gasoline engines capable of delivering from 70 horsepower for the smallest size to about 200 horsepower for the largest. In other words, if six-cylinder engines are considered, this means that the engines will range from about $3\frac{3}{4}$ -inch bore by 5-inch stroke to perhaps $6\frac{3}{4}$ -inch bore and 8-inch stroke. The maximum operating engine speeds will vary from 2,000 revolutions per minute to about 900 revolutions per minute. These engines are practically all larger than those commonly used in automobiles and trucks. At the present time engines which have been developed for the bus and rail-car industries are being adapted to fire service, but not without some very necessary changes in the details of manufacture.

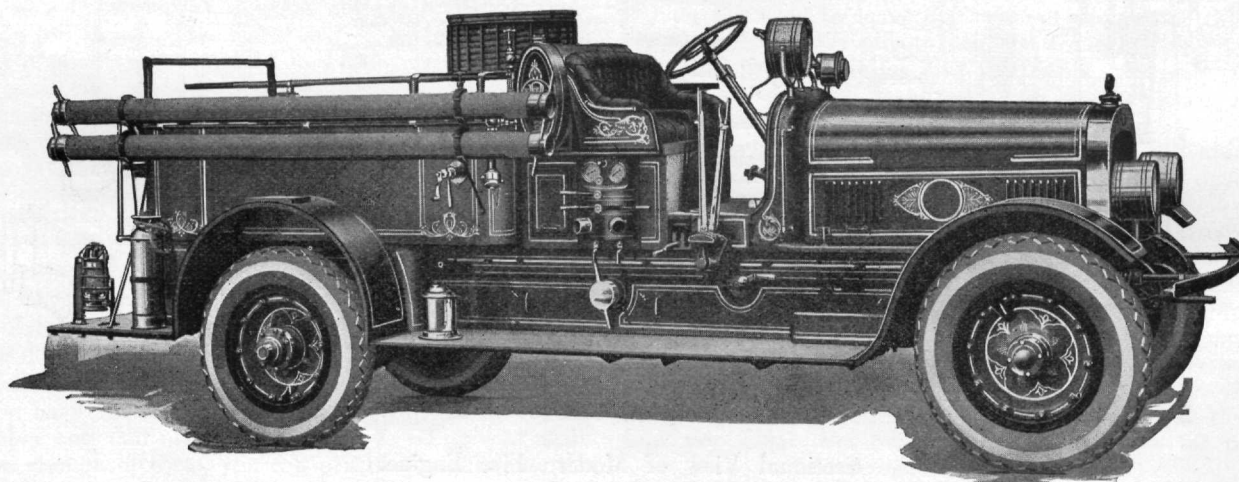
A fire engine is rated at a certain capacity when pumping at a pressure of 120 pounds per square inch,

but it must be capable of delivering one-half this volume at 200 pounds per square inch and one-third at 250 pounds per square inch. Some fire engines are capable of pumping at pressures of 350 and 400 pounds per square inch and even higher but will, of course, deliver a correspondingly less volume. The National Board of Fire Underwriters, which controls the fire-insurance rates, requires that before a certain make or model of fire engine will be recognized, one fire engine of each model must successfully pass an endurance test of twelve hours under observation of Underwriter officials. The pump is operated for a period of six hours at its full rated capacity at a pressure of 120 pounds per square inch, three hours at one-half capacity and 200 pounds per square inch pressure and the final three hours at one-third of its rated capacity and a pressure of 250 pounds per square inch. Besides this test, which is required but once for each model, each fire engine must undergo a six-hour acceptance test similar to the former test, except that the time required at each pressure is only half that in the official rating test. The fire engine must undergo these tests at approximately wide-open throttle without a serious fault, and be capable of doing that much and more in actual service. It is not an uncommon experience for fire engines to be required to operate continuously for from ten to twenty hours.

The steam fire engine brought the piston pump into great favor with the fire-fighters all over the world. When the gasoline fire engine was first conceived, it was quite natural that the piston pump should be assumed by some to be the most suitable type. This pump has been so well adapted to the modern fire engine that it is favored by many today. However, it must be said that some of this preference is a result of the performance of this type of pump on the steam fire engine and not wholly based on the present relative merits of the various types. The piston-type fire pump is directly connected to the engine and is made up of a pair of two- or three-cylinder pumps one or both of which may be operated, depending upon whether a high pressure or a large volume of water is wanted. A fire engine of this type when operating at a high pressure requires only one section of the pump, but if it is necessary to operate at a lower pressure and a much greater volume of water, both sections of the pump must be used. The pump must stop functioning for an instant to permit this shift.

The piston pump is generally located in front of the engine and is connected to the engine by means of a jaw clutch when the pump is to be operated. This location of the pump makes connections for the suction

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and discharge hose very accessible and also gives a somewhat striking appearance to the fire engine, as the pump and its large nickel-plated air chamber are mounted in front of the engine and radiator.

The most common type of pump used in fire service is the rotary-gear. It is much smaller than the piston pump and, like the centrifugal pump, is located under the driver's seat. The rotary pump is connected to the engine through a special pump transmission. The need of various delivery pressures requires changeable gear ratios for different operating conditions and necessitates shifting the gears to the proper relation of engine and pump speeds so as to insure maximum delivery at any desired pressure.

Both the piston and rotary-gear pumps are positive displacement and for this reason are desirable when it is necessary to draft water from a lake, stream or cistern. These pumps are equipped with various bypass arrangements and relief valves for regulating and governing the discharge pressure. The piston pump tends to give an intermittent flow of water, but this is partially overcome by an air chamber which helps the pump give an approximately uniform delivery. However, there are very marked pulsations in the hose lines as well as bad vibrations in the fire engine caused by this unevenness of flow. The displacement in the rotary-gear pump is not uniform during the whole pump revolution and some produce pulsations as serious as those resulting from the piston pump. An air chamber is supplied by some manufacturers to partially correct this trouble.

The centrifugal pump is not of the positive-displacement type, but delivers the water by imparting to it a high velocity which is changed to pressure as the water passes through the pump casing. When a pump of this type is correctly designed, the flow of water will be free from pulsation and the whole fire engine very free from vibration. The pump is driven through a pair of gears selected to give the proper speed relation between the pump and the engine. This gear ratio is fixed for all deliveries and pressures. The variation of pressure is accomplished by only varying the quantity discharged. An increase in pump pressure is accompanied by a slight increase in the pump and engine speeds. Even though the discharge valves were completely closed, the pump would develop a certain pressure dependent upon its speed but would not require any relief valves such as are necessary on positive displacement pumps. When it is necessary to pump water from a stream or other source, the centrifugal pump cannot deliver water until it has first been primed or the pump and suction pipe filled with water. The manufacturers of fire engines equipped with centrifugal pumps have overcome this difficulty by installing a priming or vacuum pump of the positive-displacement type. Although this second pump and its drive add somewhat to the complication of the apparatus, this type of fire engine is capable of delivering a steady stream and also of priming itself. The auxiliary priming pump, which operates only when priming the fire pump, is capable of many years of dependable service, while it is not uncommon for rotary-gear pumps after years of service to be worn so as to render priming practically impossible. Thus the centrifugal pump has been made very dependable, with the addition of a few parts, as its pumping and priming qualities will not deteriorate from wear.

The centrifugal pump fire engine has been developed primarily in the United States by The Seagrave Corporation of Columbus, Ohio, while the piston pump was developed mainly by The Ahrens-Fox Fire Engine Company of Cincinnati, Ohio, and the rotary-gear pump by

the American LaFrance Fire Engine Company of Elmira, N. Y. There are at the present time several other concerns building fire engines using one of these types of pumps. In order to give somewhat in detail the characteristics of fire-engine construction as well as the method of operation, the remainder of this article will be devoted to the description and operation of a 750-gallon Seagrave centrifugal fire engine.

The streamline appearance of the apparatus is obtained largely through the use of an aluminum dash. This casting is heavily ribbed so as to support the bell, searchlight and perhaps a siren as well as side handles and an instrument box. The frame of the fire engine is built of six-inch structural-steel channels with a truss rod under each side. The wheel base is 160 inches while the over-all length is 252 inches. The fire engine is capable of a road speed of more than 55 miles per hour, even though the weight without men or fire hose is about 10,000 pounds. From 1,000 to 1,500 feet of 2½-inch fire hose is carried in the hose body at the rear of the truck, the amount depending upon the size of body desired by the various cities.

Many fire engines carry a chemical tank of from 35 to 60 gallons capacity and 200 feet of one-inch chemical hose for small fires. A solution of bicarbonate of soda and water is carried in these tanks together with a closed bottle of sulphuric acid. When the fire is reached, the acid is dumped into the soda solution. A very high pressure is developed in the tank and is used to force the solution through the hose to the fire. Due to the great amount of damage caused by this chemical solution, there is a rapidly growing tendency toward the use of water tanks of 65 to 80 gallons capacity in place of the chemical tank. This water is pumped by the regular fire pump through the chemical hose. This method has been found to be very effective on small fires that have not gained much headway.

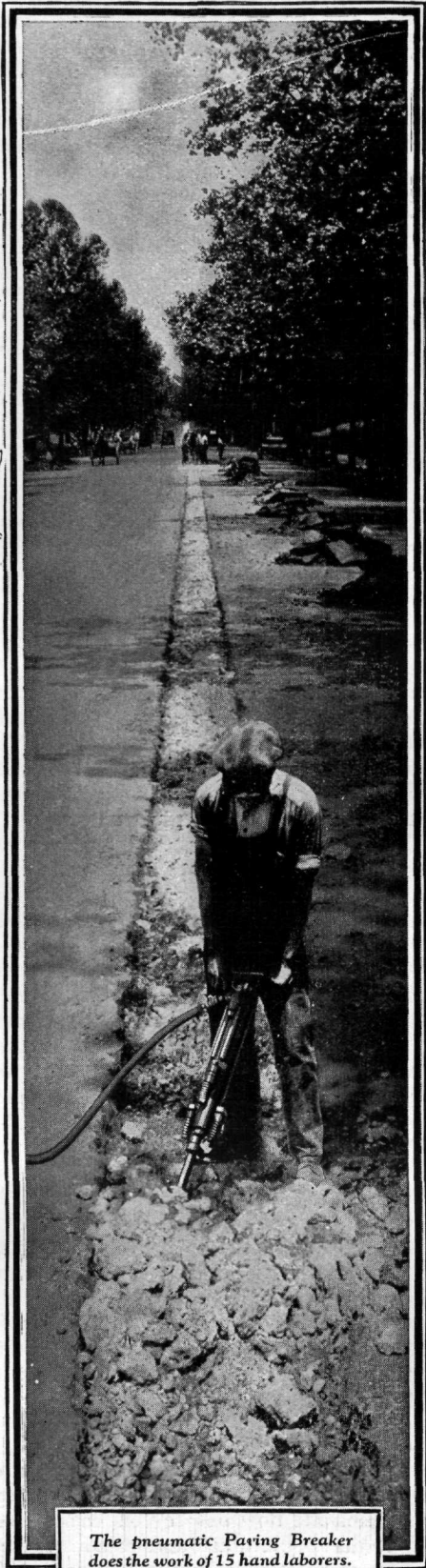
A twenty-foot extension ladder and a twelve-foot roof ladder are mounted on one side of the fire engine.

The engine used in the Seagrave 750-gallon pumper is a six-cylinder, T-head engine which has the cylinders cast separately and mounted on a Lynite crankcase. The engine has a 5¾-inch bore and 6½-inch stroke with a piston displacement of 1,012.7 cubic inches. The S. A. E. rating is 79.3 horsepower while the engine will develop about 150 brake horsepower when operating at 1,700 revolutions per minute. The compression ratio is 4.63 to 1. Light-weight cast-iron pistons are used with four piston rings on each piston. The connecting rods are I-beam drop forgings and have four bolts in the lower end. The bearings are 2½ inches in diameter and 2¾ inches long. The crank shaft is supported on seven main bearings of 3-inch diameter. The maximum bearing pressure on the connecting-rod bearings is 870 lbs. per square inch while that on the main bearings is 730 lbs. per square inch when operating at 1,600 revolutions per minute. Two cam shafts are used, each supported on four bearings and driven directly from the crankshaft by a pair of spur gears. The connecting-rod, main and camshaft bearings are all bronze-backed with a babbitt lining. The main and cam-shaft bearings are reamed to size in the engine crank case. The valves, which are 3¾ inches in diameter, are operated through roller-follower tappets and have a lift of ⅝ inch. The free valve diameter is 2¾ inches.

The fuel is supplied to the engine through a two-inch carburetor and a manifold which is provided with a hot spot that may be used at will.

The electrical system is 12-volt throughout. The starting motor connects through a reduction gear and Bendix drive to the flywheel gear. The ignition is sup-

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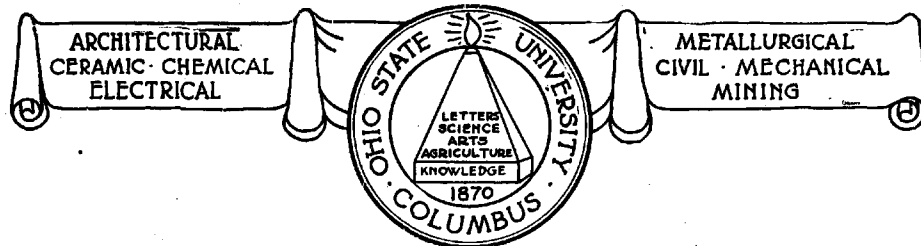
plied from two independent sources; a distributor and coil furnish the battery ignition, while a single or two-spark magneto is also provided.

A three-gear oil pump is used to lubricate the engine. This pump delivers two independent streams of oil. One of these maintains a supply of oil in troughs under the connecting rods, while the other forces oil under pressure to the main bearings. The connecting rods are provided with scuppers which take up some of the oil from the troughs for the connecting-rod bearings and splash oil on the cylinder walls and other bearing surfaces.

The water cooling system incorporates the conventional centrifugal circulating pump. However, when pumping, this system alone is very inadequate and an

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auxiliary cooler is provided through which the water passes after leaving the radiator. This auxiliary cooler consists of many small brass tubes enclosed in a case in such a way that the water passes through half of the tubes to one end of the cooler and then returns through the other half. These tubes are surrounded with water circulated by the fire pump, thus the engine cooling water is cooled while passing through these tubes. A small water line from the fire pump directly to the cooling-water system is provided so that the supply may be replenished or allowed to overflow slowly and thus aid in cooling the engine.

The clutch is a dry single-plate type, enclosed in the flywheel and capable of easy adjustment. The plate is faced on each side with an asbestos fabric clutch lining. The actuating pressure for the clutch is produced by several small helical springs. As the clutch wears, there is a tendency for it to slip and thus require adjusting. This slipping might not be evident until pumping at a fire and then there would be no time available to adjust the clutch. To guard against such an emergency, a clutch lock is provided which will prevent any slipping and transmit the power directly to the pump.

The road transmission is built as a unit and is located near the rear axle. There are three speeds forward and one reverse and they are obtained through the standard automobile gear-shift positions. Stub-tooth gears of 5-7 pitch with $1\frac{3}{4}$ -inch face are used and the shafts are supported on large ball bearings. The power is transmitted to the rear axle through an all-metal type double universal joint.

A worm-drive rear axle is used with a Hotchkiss-style drive. The speed reduction in the rear axle is $4\frac{1}{2}$ to 1 or 5 to 1. Taper roller bearings are used throughout the worm-drive rear axle as well as the pivot supports of the front axle. The brakes are all internal expanding and act on the rear-wheel brake drums. Cast-steel disc wheels are furnished as specified by the purchaser and are mounted on taper-roller bearings.

Both two-stage and four-stage centrifugal pumps are used in this make of fire engine, the two-stage is the one used in the 750-gallon pumper. All parts of the pump that come in contact with water are made of bronze. The pump is made up of a large barrel-shaped body, the two heads, the diffuser rings, and the rotating parts, which consist of the impellers and shaft. The body contains all of the water passages from one impeller to the next as well as two suction and two discharge passages. Each head contains a ball bearing and a packing gland.

A gear on the pump shaft is in mesh with a gear that may be connected to the main drive shaft when the pump is to be operated. The pump shaft is supported on two ball bearings, one is a deep-groove type while the other is a double-row combined radial and thrust type. This arrangement takes care of any unbalanced end thrust in the pump. On the opposite side of the pump transmission is the priming pump. This is an eccentric-vane type of positive displacement pump, and is capable of priming the fire pump at lifts of over 25 feet in less than a minute.

The pump-transmission gears are 4-pitch, $14\frac{1}{2}$ degree involute with $2\frac{1}{2}$ -inch face. These gears are ground after heat treatment to lessen the noise of operation, as they sometimes have pitch-line speeds over 4,000 feet per minute. The gears are free when the apparatus is on the road and are connected to the drive shaft by a special type three-jaw clutch. The priming pump is connected, when needed, to the end of the centrifugal-pump shaft by a second jaw clutch. The pump and transmission are mounted under the driver's

seat. This assembly and the exhaust pipe are enclosed by sheet-steel walls in order to prevent freezing in the winter.

The pump is controlled by means of a lever on the right-hand side of the apparatus. When this lever is raised, the main clutch is released. With the clutch out the lever may be pushed sideways to engage the jaw clutch that drives the pump transmission. When the lever is lowered, the gears and pump are put in motion. If the pump is to draft water, the priming pump must be used, and it is controlled by a latch on the control lever. This latch is pressed down when shifting sideways to engage the pump transmission. The latch is then held down until water has been obtained, when it is released so that the priming pump may stop. This control system also operates a valve connecting the centrifugal pump and the priming pump while priming. Thus with this unified control system, one lever controls all operations. There are other levers nearby for controlling the fire streams, auxiliary cooler and pressure regulator.

Centrifugal fire pumps are made as small as possible, due to the limited space available for installation, but even then the pumps have maximum efficiencies of 70 to 75 per cent. A centrifugal pump is designed to operate at some certain pressure, but, for a fire engine where the pressure may vary from 120 to 350 pounds per sq. in., this design pressure is very difficult to determine and is based in a great part on experience. Another very important item in centrifugal fire engine construction is the determination of the proper gear ratio between the pump and engine. This ratio must correlate the variations in engine torque and pump efficiency so that the maximum volume of water may be obtained at the various pressures.

The engineering problem in fire engine manufacture is greater than would be expected, due to the number of models of apparatus produced. For instance, one manufacturer builds seven sizes of fire engines, which require five sizes of engines. Along with this there are about ten models of combination cars, service (ladder) trucks, aeriels and water towers. This makes a total of seventeen models, many of them coming through the shop at one time. Besides this, practically all cities have many special features which they insist must be incorporated in their machines, such as special styles of bodies and equipment. In fact, anything except the engine, pump, transmission and axles, is subject to the requirements of the various cities. Production methods are applied to the manufacture of the standard units, but with much difficulty, as the great volume of special work tends to disrupt such routine. Individual shop specifications are required for each fire engine built, that is, they are "custom built."

In present-day production, it is surprising that the cities should insist upon special fire engines,—insist that the manufacturer building to suit the various cities, with the result that the people pay perhaps twenty per cent more for practically the same thing. Why should not the manufacturers discontinue building special fire apparatus? They should, but the writer believes the initiative must be taken by the cities.

Great development has been made in fire apparatus in the last few years, but, like most other industries, much improvement is still needed. This fact is realized when one considers that the annual fire loss in the United States is over \$500,000,000, and that more than 15,000 people lose their lives in fires each year. It is to be hoped that these figures may decrease in future years with the aid of improved fire-fighting methods and more effective fire engines.